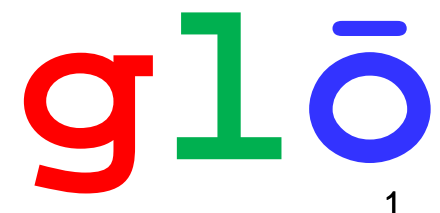


# Nanowire LEDs for RGB Lighting

*Nathan Gardner  
Glo-USA, Inc.*



# Driving the SSL revolution

- Advantages of RGB+ to phosphor-converted approach:
  - Higher ultimate LED package efficiency (lm/W)
  - Tunable color
- Competition for linear fluorescent

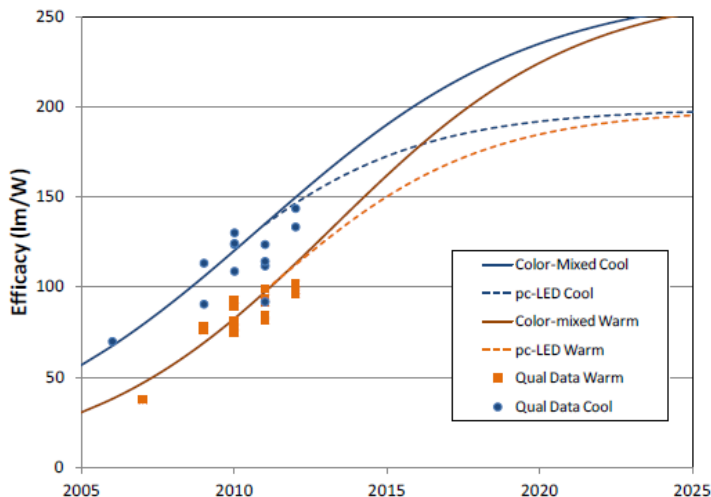


Figure 5.5: White Light LED Package Efficacy Projections for Commercial Product

Notes:

1. "Qualified" data points are confirmed to satisfy the following criteria or may have been normalized for current density if not reported at 35 A/cm<sup>2</sup>.
2. Cool White: CRI 70-80; CCT 4746-7040K
3. Warm White: CRI 80-90; CCT 2580-3710K
4. Current density: 35A/cm<sup>2</sup>
5. These results are at 25°C package temperature, not steady state operating temperature. Thermal sensitivity may reduce efficacies by as much as 24 percent or so in normal operation, depending on luminaire thermal management.

Table 5.5: Tabulated Progress Projections for LED Package Efficacy (lm/W)

Metric	2011	2013	2015	2020	Goal
Cool White (Color-mixed)	135	164	190	235	266
Cool White (Phosphor)	135	157	173	192	199
Warm White (Color-mixed)	97	129	162	224	266
Warm White (Phosphor)	98	126	150	185	199

Notes:

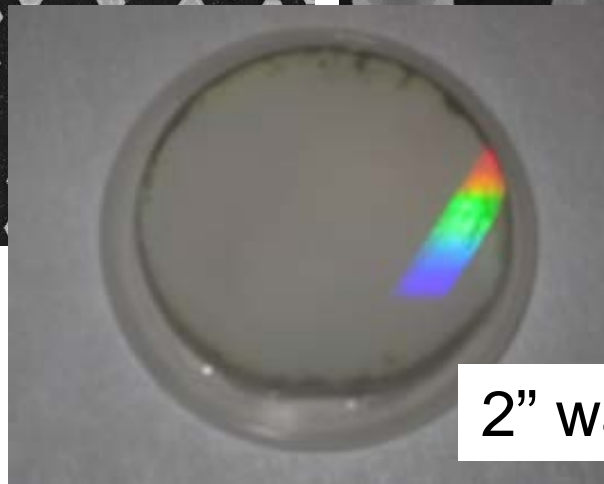
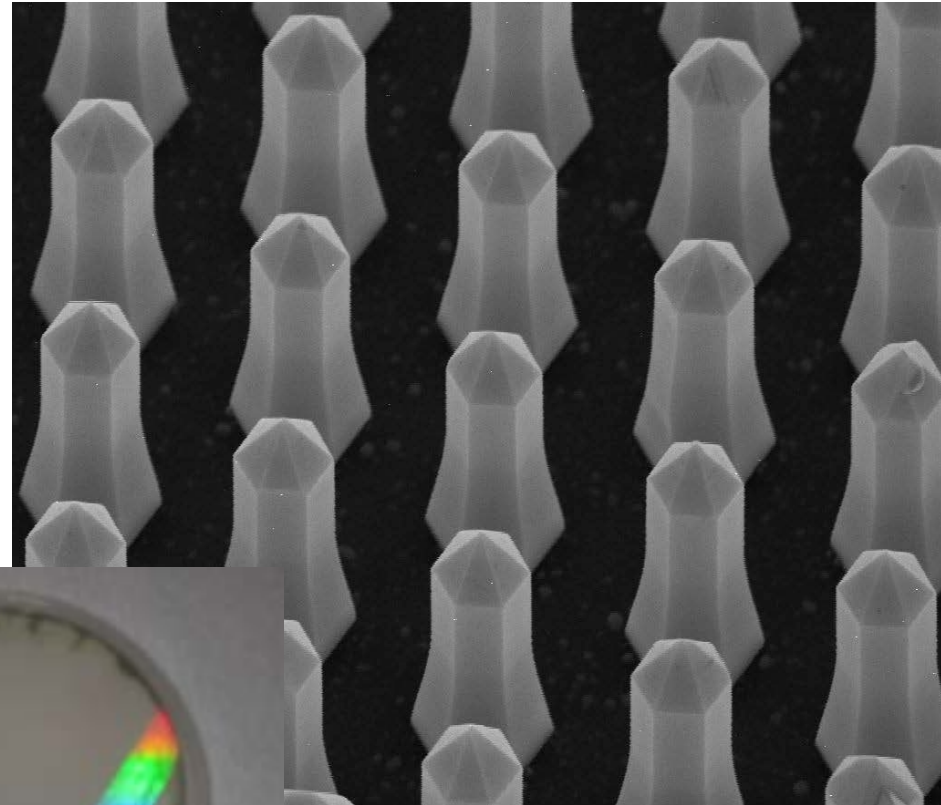
1. Projections for cool white packages assume CCT=4746-7040K and CRI=70-80, while projections for warm white packages assume CCT=2580-3710K and CRI=80-90. All efficacy projections assume that packages are measured at 25°C with a drive current density of 35 A/cm<sup>2</sup>.
2. Asymptote for color mixed is 266 lm/W, and for phosphor-converted is 199 lm/W

U. S. Department of Energy, *Solid-State Lighting Research and Development: Multi-Year Program Plan*,  
April 2012

# Arrays of Nanowires

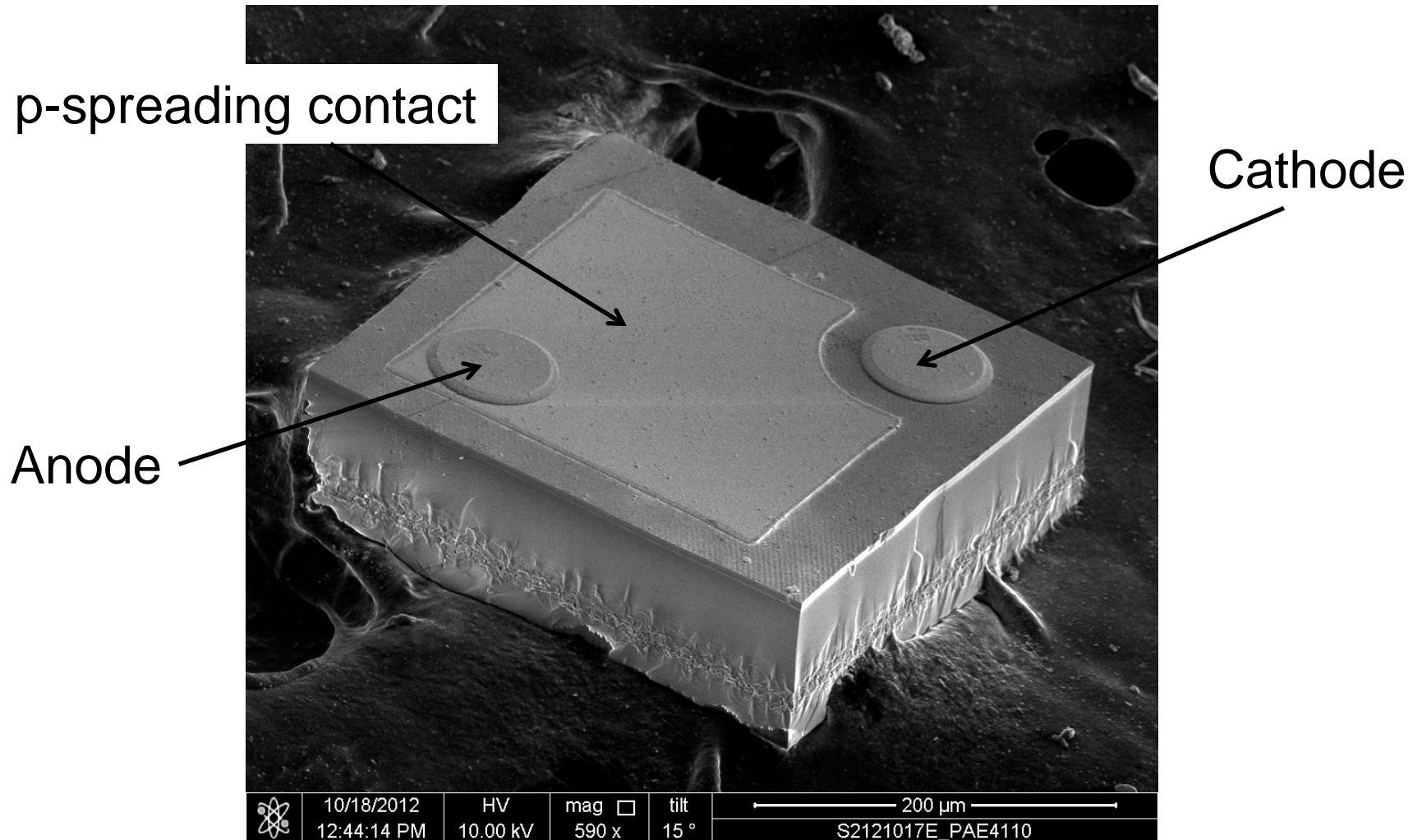
Plan View

Tilted View



2" wafer of nanowires

# Nanowire LED



# Why Nanowire LEDs?

## Main advantages:

- Active regions deposited on dislocation-free core
- Non-polar side facets
  - Less efficiency droop, helps with “green gap”
- Strain relaxation
  - More efficient green, amber, and red emitters
- Larger active region surface area, relative to substrate surface area

# Green Gap

- InGaN should be great in the green! No indirect conduction band minima near the  $\Gamma$  minimum, as in AlInGaP
- Arguments proposed over the years as to why InGaN green does not meet our expectation:
  - Large bond distortion for In incorporation  $\rightarrow$  film grown at low temperatures, causing other point defects to form (SRH centers)
  - Low radiative recombination efficiency due to quantum-confined Stark effect
  - Higher Auger recombination rate
- Why nanowires might help
  - 3D surface  $\rightarrow$  strain relaxation
  - Higher radiative recombination rate  $\rightarrow$  SRH less important ; carrier density kept below point where Auger kicks in

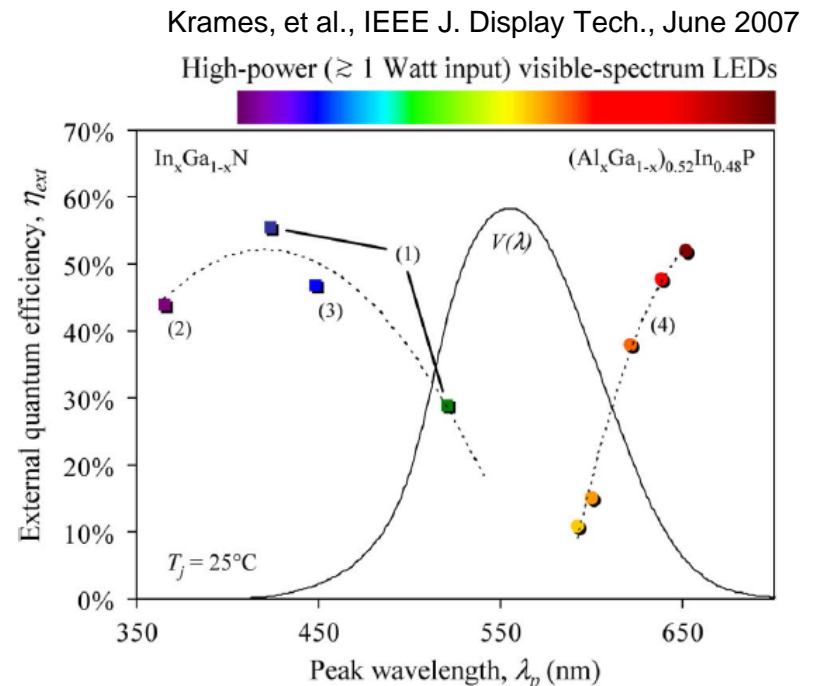


Fig. 2. State-of-art external quantum efficiencies for high-power visible-spectrum LEDs ( $T_j = 25^\circ\text{C}$ ): (1) InGaN TFFC LEDs, 350 mA (this paper); (2) InGaN VTF LED, 1000 mA [42]; (3) InGaN CC LEDs employing patterned substrates [35]; and (4) Production performance, AlGaInP TIP LEDs [9], Philips Lumileds Lighting Co., 350 mA.  $V(\lambda)$  is the luminous eye response curve from CIE. Dashed lines are guides to the eye.

# Efficiency Droop and the Green Gap

- Efficiency droop and the green gap—the same underlying device physics problem

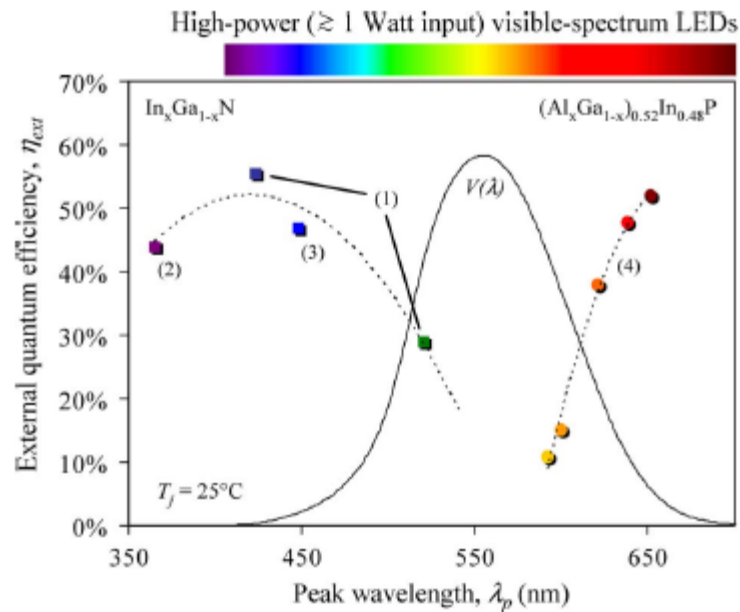


Fig. 2. State-of-art external quantum efficiencies for high-power visible-spectrum LEDs ( $T_j = 25^\circ\text{C}$ ): (1) InGaN TFFC LEDs, 350 mA (this paper); (2) InGaN VTF LED, 1000 mA [42]; (3) InGaN CC LEDs employing patterned substrates [35]; and (4) Production performance, AlGaInP TIP LEDs [9], Philips Lumileds Lighting Co., 350 mA.  $V(\lambda)$  is the luminous eye response curve from CIE. Dashed lines are guides to the eye.

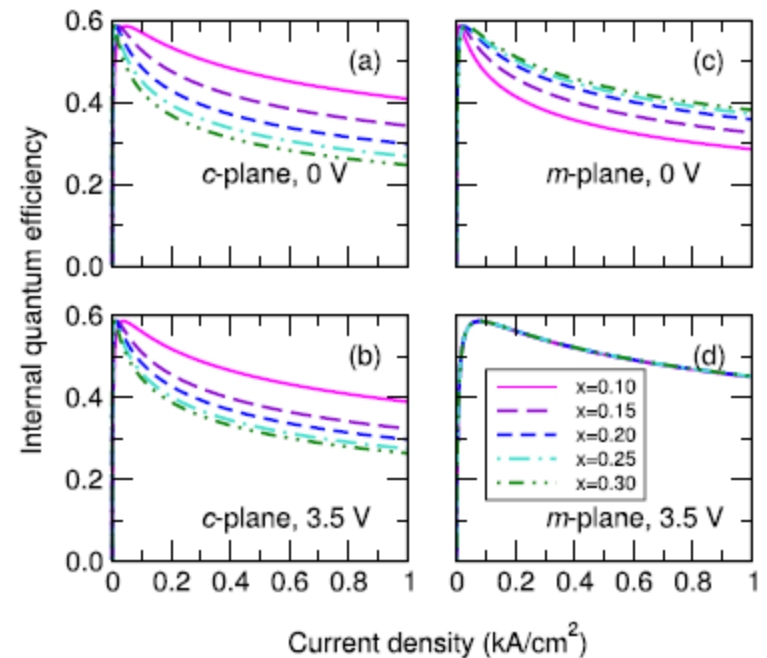
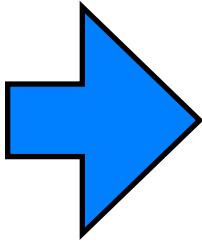


FIG. 3. Calculated internal quantum efficiency versus current density for c-plane [(a) and (b)] and m-plane [(c) and (d)] growth, under zero bias [(a) and (c)] or a 3.5 V applied voltage [(b) and (d)]. The polar c-plane device shows the characteristic droop and green-gap problems (b). The nonpolar m-plane LED displays much better performance (d).

# Next Generation LED-based Bulbless Luminaires



Today's LED bulbs  
will morph  
into ...



Bulb-less, free form  
luminaires



Bulb-less, luminous  
wall coverings

# Remove Barriers to RGB+ Lighting

- High-efficiency green LEDs & temperature-stable high-efficiency red LEDs
  - Nanowires
  - Engineered substrates
  - Bulk m-plane substrates
  - Etc.
- A demonstration of a high-quality RGB+ lighting system
  - Flux, lm/W, color stability, color tunability
  - A system for office or commercial lighting; not decorative lighting
  - Address skepticism about efficiency, lifetime, and value of tunability
- An open standard for system control
  - Reduce market fragmentation